ORIGINAL ARTICLE

Thermoregulatory observations in soccer match play: professional and recreational level applications using an intestinal pill system to measure core temperature

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Background: Technological limitations associated with oesophageal and rectal temperature probes have previously limited match play observations of body temperature.
Objective: To investigate the application of an intestinal pill system to measure core temperature during dynamic, field based, soccer matches.
Methods: Core temperature (T_c) was assessed using the intestinal pill system (CorTemp 2000) and changes in plasma volume were calculated using the values for haemoglobin and packed cell volume obtained before and after recreational (n = 8) and the professional soccer (n = 7) matches.
Results: In the recreational match, there were significant post-match reductions in body mass (−1.6%, $p<0.05$) and plasma volume (−7.2%, $p<0.01$). Significant increases were observed in T_c from rest to half time ($p<0.01$) and from half time to full time ($p<0.05$). In the professional match, body mass decreased by 1.9% ($p<0.05$) and plasma volume by 11.6% ($p<0.01$). T_c increased from rest to half time ($p<0.01$) but was unchanged from half time to full time. Significant associations were observed between maximum oxygen consumption and match play heart rates in the second half of each match but these were not related to changes in plasma volume or T_c.
Conclusions: Intestinal temperature proved a useful method of recording core temperature during soccer match play and assisted in the measurement of alterations in thermoregulatory variables in response to both professional and recreational level soccer matches; however, technological limitations still restrict the wider application of this method, especially at a competitive level.

The thermoregulatory stresses associated with soccer match play have typically been estimated by focusing on the responses to match simulation in laboratories or a controlled interior environment.[1–3] In out of doors match play, soccer players are exposed to environmental conditions that increase heat loss—particularly through convective cooling[4]—as the evaporative capacity of the environment is increased with higher air velocities over those experienced in laboratories with near windstill conditions. Also, the competitive element of match play involves an intensity of physical challenge and psychological stress that is difficult to replicate in a laboratory. For these reasons the two settings are not strictly comparable. A few studies have examined thermoregulatory responses before and after soccer match play[5–7] but, to our knowledge, no studies have reported core temperatures during match play, presumably because of the technological limitations involved in making oesophageal or rectal measurements.

Successful performances in intermittent high intensity sports such as soccer are characterised by the ability to sustain high work intensities over the duration of the game. The average work intensity during a soccer match has been estimated to approximate ~80% of maximum aerobic power ($\dot{V}O_2$ max)[8 9] and this level of intensity broadly resembles typical values of anaerobic threshold measurements.[10 11] It is possible that sustained high intensity work rates during match play might reflect either a greater thermal strain on the player or a favourable physiological adjustment for the purposes of effective heat dissipation.

Under most match conditions, the pre-match to post-match weight loss of adult male soccer players averages around 2% of body weight;[12] an amount that has previously been associated with decrements in cognitive function[13] and psychomotor performance.[14] Studies of the effects of fluid loss on exercise performance have also reported increases in core temperature, cardiovascular strain, and a decreased blood volume.[15 16] These observations may have implications for sustained high intensity work and decision making during competitive match play. It is therefore surprising that few studies have reported core temperature measurements in response to soccer match play, though technological limitations surrounding oesophageal and rectal temperature procedures may have contributed to this. Thus the measurement of core temperature using an intestinal pill system[17–20] presents an intriguing opportunity to evaluate match play responses in more dynamic settings than previously possible.

Our aim in this study was to examine the thermoregulatory responses to soccer match play in performers at different levels of the sport using a practical and innovative method for the assessment of core temperature.

METHODS

Subjects

Before any testing, all subjects provided informed consent for their participation, in accordance with local university ethics committee and the code of ethics of the World Medical Association (Declaration of Helsinki 1975).

Eight male university students from a recreationally active collegiate soccer team (Rec) agreed to participate in the recreational match (mean (SD) age, 20 (2.2) years, height 179.3 (1.9) cm, and weight 81.1 (3.9) kg) (part A) and seven first team soccer players (Pro) from an English Championship Division team (24 (3) years, 179.4 (4) cm, 74.4 (4) kg) agreed to participate in the professional match (part B).

Baseline cardiopulmonary fitness was assessed in all subjects over two week periods before participation in either match. All subjects completed an incremental test to volitional exhaustion on a treadmill (Woodway PPS 55, Weil am Rhein, Germany) for the assessment of $\dot{V}O_2$ max. Gaseous exchange was measured breath by breath at the mouth (Cortex Metalyser 3B, Cortex Biophysik, Frankfurt, Germany).

Core temperature

Core temperature (*Tc*) was measured in the intestine using a silicon coated pill (CorTemp, Human Technologies International, Glendora, California, USA). Each pill contains a crystal quartz oscillator which transmits a low frequency radio wave to an external receiver/data logger. The calibration of the ingestible pills was checked at four different temperatures against a certified mercury thermometer in a water bath at temperatures ranging from 30° to 42℃. A linear regression of the relation between the measured temperatures and those from the certified thermometer was used post-test to adjust pill measurements. The ingestible pill was swallowed approximately four hours before the matches to ensure that it would be past the stomach and insensible to swallowed hot or cold liquids. Subjects ingested the pill at the same time as a small meal and consumed only water thereafter.

Soccer match play

In the recreational match, the eight participants comprised the majority of the same starting team in an 11-a-side, friendly intercollegiate fixture, in front of approximately 20 spectators. All participants completed the full match duration. The match was played in the mid-afternoon at a constant ambient temperature of 16℃ and barometric pressure of 760 mm Hg with a relative humidity of 47%. In part B, the seven professional players all completed the full pre-season friendly match in front of 14 853 spectators, and against English Premier League opposition. The match was played in the evening at a constant ambient temperature of 19℃ and barometric pressure of 765 mm Hg with a relative humidity of 53%.

On match days, each player was weighed, after voiding, in underwear one hour before the start of the game. After being weighed, the players were allowed to drink water ad libitum both before the game and during the half time interval. Upon completion of each game, the players were towel dried to remove surface sweat and then weighed in underwear.

In both parts of the study, heart rates were recorded at five second intervals throughout games by the Polar Heart Rate Team system (Polar, Kempele, Finland). Heart rate data were batched into the mean of five minute intervals for the purposes of statistical comparisons with other match play and baseline fitness variables. In the recreational game, six periods of around 30 seconds were removed from heart rate data averaging, corresponding to periods of inactivity during core temperature assessments.

In part A, access to players was readily available and so T_c was measured as follows: one hour before the match, following the warm up (Pre-5 min), and immediately following each half. Intra-half measurements of T_c were recorded at 10 minute intervals, for which individual players were taken out of the game for approximately 30 seconds and replaced by a substitute player. Each collection period was concluded within around three to four minutes. In the professional game access to players was restricted and core temperature was measured one hour prior to the game and immediately following each half. Unfortunately, T_c was only measured in four of the seven players at the half time interval as three players were unavailable while receiving tactical instruction from the coaching staff.

Blood sampling and analysis

Blood was sampled from the fingertip at rest before testing, and immediately following match play. A small incision was made using a single use disposable lancet (Microtainer; Becton Dickinson, New Jersey, USA) and 35 μl of whole blood were immediately analysed for lactate concentration (Analox GM7 Analyser, Analox Instruments, London, UK). Duplicate sampling was carried out on a further 10 μl of capillary blood using a dual wavelength photometer (HemoCue, Derbyshire, UK) for the haemoglobin concentration. Packed cell volume was estimated as the mean of duplicate samples of 75 μl of capillary whole blood, using a Hawksley microcentrifuge and reader card (Hawksley and Sons, Lancing, UK). Change in plasma volume from pre-match to post-match was assessed by the method described by Dill and Costill.[21]

Statistical analyses

All data are presented as mean (SD). As the two soccer matches took place in different environmental settings, statistical comparisons were not made between matches. Thus changes in temperatures and heart rates during the two games were evaluated by one way analysis of variance (ANOVA) with repeated measures. Independent sample *t* tests were used to compare baseline fitness measurement between groups and Student's paired *t* tests were used to assess pre-match and post-match observations in the professional match for both core temperature and plasma volume ($n = 7$). Pearson's product-moment correlation test was also used as appropriate. The significance level was set at $p<0.05$.

RESULTS

Baseline measurements

Maximal aerobic power measurements were significantly greater in Pro (part B) than in Rec (part A) (table 1, $p<0.01$). The oxygen uptake and heart rates achieved at ventilatory threshold (T_{vent}) were also significantly higher for Pro and represented higher percentages of both $\dot{V}O_2$max ($p<0.01$) and maximum heart rate ($p<0.05$) (table 1).

Part A: Responses to a recreational soccer match

The averaged heart rates for the first five minutes of each half were significantly lower than all other measurements ($p<0.05$) (fig 1). Peak heart rates were attained after the first five minutes of the first half and were sustained close to this level until 20 minutes. These measurements remained increased in comparison with all other phases of the first half but the difference was not statistically significant. A pattern for an earlier peak heart rate was also evident in the second half, where the highest heart rates were attained at an average of 70–75 minutes. There was no statistical difference between the second half heart rates, although the mean heart rate for the first half (159.2 (3.9) beats/min) was significantly higher than the corresponding average for the second half (153.2 (3.3) beats/min) ($p<0.05$). The average percentage of maximum heart rate over the first half was 82%, which was significantly higher than for the second half (79%; $p<0.05$).

Body mass decreased significantly over the course of the match and represented a 1.6% loss in weight ($p<0.05$) (table 2). The estimated plasma volume decreased from rest to full time by 7.2 (1.7)% ($p<0.01$) and blood lactate concentrations increased significantly from rest (1.6 (0.4) mmol/l) to post-match (5.3 (1.5) mmol/l) ($p<0.01$) but were not significantly related to any other variable.

Average T_c in the recreational soccer players showed a trend for higher temperatures as the game progressed (fig 2).

Table 1 Baseline cardiopulmonary fitness measurements for professional and recreational level soccer players

	$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	Maximum heart rate (beats/min)	T_{vent} ($\dot{V}O_2$) ($ml \cdot kg^{-1} \cdot min^{-1}$)	Heart rate at T_{vent} (beats/min)	Heart rate (% of max)
Recreational (n = 8)	52.73 (4.1)	192.9 (3.4)	37.03 (3.9)	149.4 (6.6)	77.4 (3.3)
Professional (n = 7)	65.62 (4.9) **	190.5 (2.6)	50.97 (5.1)**	158.8 (6.4)*	83.4 (2.5)*

Values are mean (SD).
*Significant difference between recreational and professional soccer players (parts A and B respectively), $p<0.05$.
** Significant difference between groups, $p<0.01$.
T_{vent}, ventilatory threshold; $\dot{V}O_2max$, maximum aerobic power.

The highest measurements were recorded in the latter phase of the second half and immediately following the game (fig 2). Core temperature was significantly raised from the resting level at the 20 minute measurement point ($p<0.01$), and remained increased at 30 minutes ($p<0.01$) and at the conclusion of the first half (45 minutes; $p<0.01$). In the second half, T_c was significantly raised from resting levels at 80 minutes ($p<0.05$), 90 minutes ($p<0.05$), and full time (105 minutes) ($p<0.01$). Core temperatures recorded at full time were significantly increased from half time ($p<0.05$).

There were significant associations between $\dot{V}O_2max$ and the average heart rate at 80–85 minutes ($R^2 = 0.46$; $p<0.05$) and also between $\dot{V}O_2max$ and the average heart rate at 90–95 minutes ($R^2 = 0.50$; $p<0.05$), but there was no significant association between $\dot{V}O_2max$ and the average heart rate in either the first or the second half. Baseline $\dot{V}O_2max$ was not related to any measurements of T_c.

Part B: Responses to a professional soccer match

In this part of the study, the heart rates recorded at the initiation of the game (0–5 minutes) were significantly lower than in all other phases of the first half ($p<0.05$), although there were no statistical differences between the other five-minute averaged intra-half heart rates over the course of the game (fig 1). The mean heart rate for the first half (164.4 (4.1) beats/min) was significantly higher than the corresponding average for the second half (159.1 (2.9) beats/minute) ($p<0.05$). The average percentage of maximum heart rate sustained for the first half was 86%, and 83% for the second half ($p<0.05$).

Mean body mass decreased significantly by 1.9% over the course of the match ($p<0.05$) and the estimated change in plasma volume from rest to full time was −11.6 (1.7)% ($p<0.01$). Blood lactate concentrations increased significantly from rest (1.9 (0.3) mmol/l) to post-match (3.7 (0.9) mmol/l) ($p<0.01$) but were not significantly related to any other variable.

Core temperature increased from rest to half time ($p<0.05$) (n = 4) and from rest to full time ($p<0.01$) (n = 7) (fig 2). There was no significant difference between T_c recorded immediately after the conclusion of the first half *v* the second half (n = 4). Measurements of T_c taken at full time (105 minutes) were not significantly related to pre-match cardiopulmonary fitness.

Baseline $\dot{V}O_2max$ correlated with average match play heart rate at 90–95 minutes ($R^2 = 0.55$; $p<0.05$) and with the second half average ($R^2 = 0.69$; $p<0.01$) but were not significantly related to other match play heart rates.

DISCUSSION

An interesting finding of this study was that in the two different match play settings both professional and recreational level soccer players experienced significant reductions in body weight and plasma volume from pre-match assessment to the end of each game. Weight loss was not redressed by the ad libitum intake of water in the half time intervals, which is consistent with a 40 to 60 minute time course required to improve blood volume and plasma osmolality identified by Montain and Coyle.[22] This also agrees with the time course in which that volume of water would be distributed throughout the body after gastric emptying, intestinal absorption, and osmotic flow.[23] This suggests that the ingestion of water at the half time interval may not be physiologically useful for second half performance and may

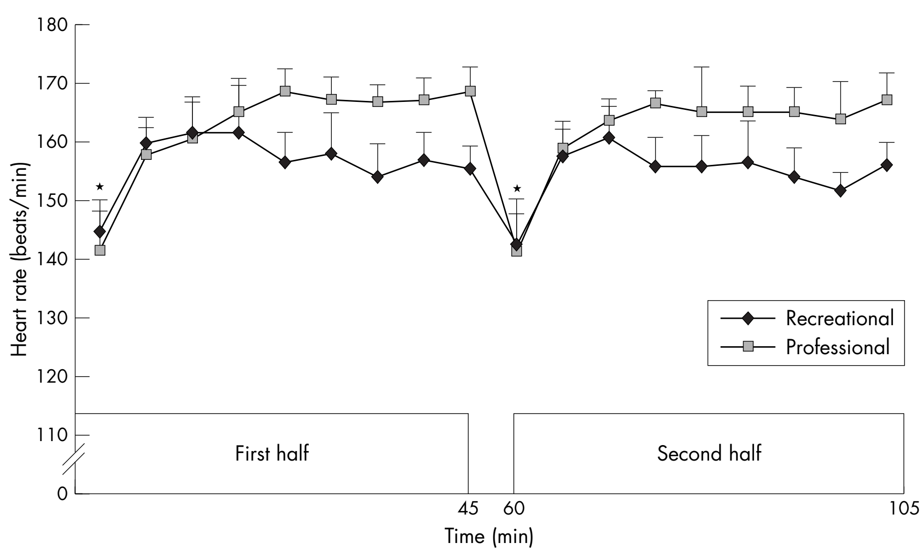

Figure 1 Mean heart rate responses to the recreational and professional soccer matches. *Significantly lower than the other heart rate measurements ($p<0.01$).

Table 2 Loss of body mass and change in plasma volume from rest to full time in response to professional and recreational soccer matches

	Body mass (kg)	Body mass loss		Plasma volume change (%)
		kg	%	
Recreational match (n = 8)	81.1 (3.9)	1.3 (0.1)*	1.6 (0.2)*	7.2 (2.1)*
Professional match (n = 7)	79.5 (2.6)	1.5 (0.1)*	1.9 (0.2)*	11.6 (1.7)**

*Significant change from rest to full time, $p<0.05$.
**Significant change from rest to full time, $p<0.01$.

reduce any benefit of carrying a progressively reduced body weight during the game. However, the ad libitum design used for water replacement in this study is a limitation on the accuracy of the estimation of total body water loss.

A recent study[5] reported moderate dehydration of soccer referees over the course of a game, with an associated 5% reduction in plasma volume ($p<0.05$). In this study, the magnitude of plasma volume loss during both match play settings was greater than reported previously in referees (part A: −7.4%, $p<0.01$; part B: −11.6%, $p<0.01$), reflecting the greater dynamic demands of match play and sustained exercise intensities. Exercise modifies the balance between the forces that determine the distribution of body water in the intracellular and extracellular compartments, and reductions in plasma volume could lead to a reduction in the blood supply both to exercising muscles and to the skin, thus reducing oxygen transport to the working muscles while also diminishing the ability to dissipate heat as body water deficit increases.[24] However, as it is sweating that produces the greatest heat loss during exercise, the greater losses in plasma volume and body weight suggest that a more pronounced sweating response may have been initiated in the professional players to promote whole body cooling. Interestingly, core temperature continued to increase significantly from half time to full time in the recreational players (fig 2) whereas it reached stability from the first to the second half in the professional players. It is likely that this reflects superior heat acclimatisation in the professional players, offering the advantageous match play adaptation of a lighter body weight to carry as the game progresses.

It is generally conceded that an increase in ambient temperature and relative humidity stimulates body fluid loss[25]; however, in this study the two matches were played in similar conditions (16℃ and 19℃; 47% and 53% relative humidity), and so although the two settings are not directly comparable owing to various additional environmental factors (the number of supporters, the status of the game, wind strength, and so on), it would be logical to assume that the professional players are more experienced in match play and can thus pace themselves more effectively over the course of a game. A previous study[6] reported unchanged rectal temperature between half time and full time in low league Danish professional soccer players. It is possible that the more highly trained professional players in this study adjusted to the match play conditions by initiating a more pronounced sweating response to promote whole body cooling through evaporation—hence the greater losses of body mass and plasma volume. However, further research is

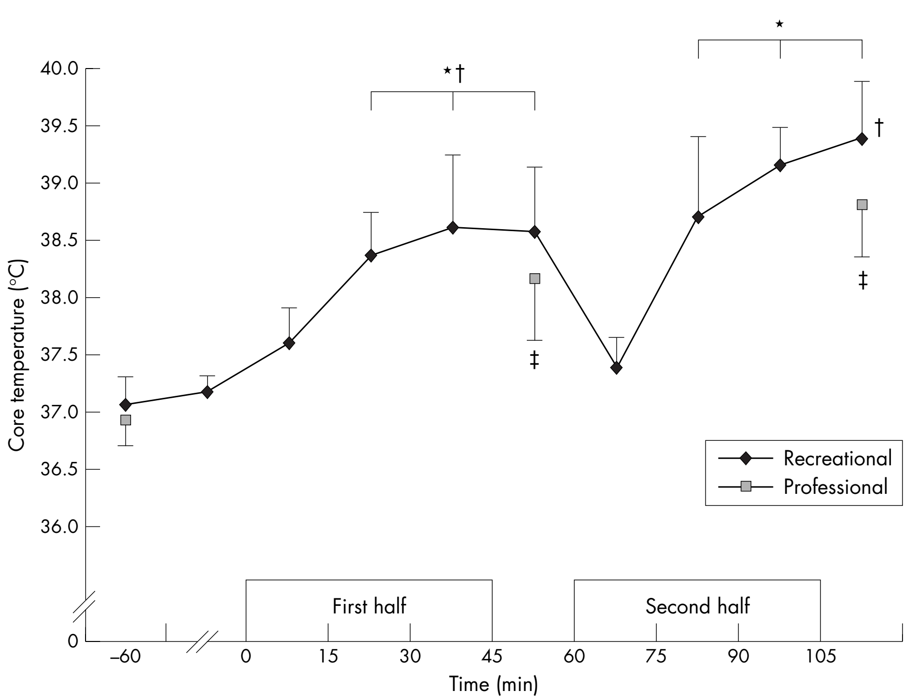

Figure 2 Change in core temperature from rest to full time in recreational and professional soccer matches. *Significant difference between resting core temperature and match play measurements in the recreational players ($p<0.01$). †Significant difference between first and second half core temperature measurements in the recreational players ($p<0.05$). ‡Significant difference from resting core temperature in the professional players ($p<0.01$).

required to confirm this observation as the small subject numbers in this study reduce the confidence in this observation.

Baseline $\dot{V}O_2$max measurements were significantly associated with match play heart rates in both parts of the study. Although the timing of significant associations between match play heart rates and baseline cardiopulmonary fitness measurements depends on various factors including tactical variations, the standard of opposition, and the status of the game, the strongest correlations were observed in the second half of each game, when fatigue is usually most influential on performance. This observation supports earlier work showing that aerobic fitness plays an important role in soccer match performance across a range of levels.[8] Earlier work[12 26] has demonstrated that soccer match intensity increases with the standard of play and therefore it is logical to assume that a greater $\dot{V}O_2$max could be expected for professional players. In this study, the baseline $\dot{V}O_2$max averaged 65.62 ml·kg^{-1}·min^{-1} for the professional players, compared with 52.73 ml·kg^{-1}·min^{-1} for the recreational players ($p<0.01$). However, previous research has not shown this to be a consistent feature between performers at different levels of the sport. Brewer and Davis[27] reported similar $\dot{V}O_2$max values of 59.8 ml·kg^{-1}·min^{-1} and 59.6 ml·kg^{-1}·min^{-1} for full and semi-professional English players, while more recently, Edwards *et al*[11] demonstrated unchanged $\dot{V}O_2$max values in elite professional soccer players over the course of five weeks from on- to off-seasons. This suggests that although cardiopulmonary fitness is of importance, it is likely to be one of several factors having a significant influence on successful soccer performance.

Post-match blood lactate concentrations were not associated with any other variables in either part A or B of this study although they were similar to most investigations.[26 28] Blood lactate concentration is known to be largely determined by the activity immediately preceding measurements and it is possible that the work intensity in the final minutes of each game was not sufficient to maintain high concentrations of blood lactate. This could also be attributable to various other factors such as individual variations in the number of high intensity bursts performed by the players at different stage of the games, positional and tactical influences on performance, or the delay from the final whistle (full time) to measurement, which may have acted to clear a proportion of the accumulated blood lactate.

The measurement of core temperature by the intestinal pill method proved a novel approach to quantifying thermoregulatory responses to soccer match play, where opportunities have previously been limited by time delays in the measurement of rectal temperature.[6] The intestinal pill system is less intrusive and provided a unique opportunity to assess core temperature in a professional soccer match in front of nearly 15 000 spectators. To our knowledge, no other studies have reported T_c at discreet intervals during match play, for reasons presumably attributable to technological limitations of rectal and oesophageal measurements. Nevertheless, difficulties remain in direct comparisons between match play measurements as, in this study, each collection point represented disturbances to the match, and access to players during professional match play will clearly prevent intramatch measurements until the remote transmission technology can facilitate measurements that avoid match disturbances.

A further limitation to the use of the ingestible pill is the location of the pill in the intestinal tract, which may influence temperature and the measured response. In the early stages of digestion, the pill is located in the stomach or upper intestinal tract, at which time it could be influenced by the ingestion of food, saliva, or liquids. In earlier studies,[29 30] subjects swallowed the pill two to three hours before data collection and these reports suggested that pill temperature could be subject to variation as it passes through the intestinal tract. Alternatively, O'Brien *et al*[20] suggested that greater stability of measurement could be achieved after waiting for 12 hours after pill ingestion before starting data collection. The four hour time for pill ingestion chosen in this study was intermediate between previous studies, and Sparling *et al*[31] found no difference between rectal and intestinal temperatures during rest and exercise in subjects who swallowed the pill three to four hours before exercise and those who swallowed the pill eight to nine hours before exercise. Therefore, although limitations remain with the ingestible pill, it presents an exciting opportunity to examine individual thermoregulatory responses to field based exercise scenarios.

In conclusion, the ingestible pill system was a useful method for assessing core temperature in soccer match play, although technological issues remain in applying this technology in professional situations where measurement opportunities are restricted. Nevertheless, the data reported in this study appear unique in match play settings. Although limited by small numbers, our results suggest that both recreational and professional soccer players exhibit have weight loss (1.6% to 1.9% of body mass) and plasma volume loss (7.4% and 11.6%) over the course of a match. Despite performing in front of nearly 15 000 spectators, the professional players were able to pace themselves at a level approximating ventilatory threshold while also stabilising core their temperature. This suggests greater heat acclimatisation in the professional players, probably mediated by beneficial training adaptations and regular elite match play performance.

What is already known on this topic

- The thermoregulatory stresses associated with soccer match play have typically been estimated from responses to match simulation in laboratories or controlled interior environments.
- A few studies have examined thermoregulatory responses before and after match play but none has reported core temperatures during match play, presumably because of technological limitations.

What this study adds

- The measurement of core temperature by the intestinal pill method proved a novel approach to quantifying thermoregulatory responses to match play where opportunities have previously been limited.

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